FAO Fisheries Technical Paper, No. 141
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Inland Fishery Resources Management

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WATER- AND LAND-USE DEVELOPMENT AND THE AQUATIC ENVIRONMENT- PROBLEMS AND SOLUTIONS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

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MAST	Information on methods and subjects
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IT	Limnological data
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MFS	Provisional editions of "FAO Manuals in Fisheries Science"
WAFR	Provisional reviews of fisheries resources and their level of exploitation, by regions or by species groups, within the World Appraisal of Fishery Resources system

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MFS	Editions provisoires des «Manuels FAO de science halieutique»
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IT	Sinopsis sobre limnología
	y

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CB	Listas de periódicos, secciones especiales de la «Aquatic Sciences and Fisheries Abstracts (ASFA)», bibliografías especiales y trabajos relativos a los problemas de documentación
MFS	Ediciones provisionales de los «Manuales de la FAO de Ciencias Pesqueras»
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Inland Fishery Resources Management

WATER- AND LAND-USE DEVELOPMENT AND THE AQUATIC ENVIRONMENT - PROBLEMS AND SOLUTIONS

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, June 1975

PREPARATION OF THIS DOCUMENT

This publication is a revision of:

> Dill, W.A., D.W. Kelley and J.C. Fraser (1971)
> The effects of water- and land-use development on the aquatic environment and its resources and solutions to some of the generated problems. FAO Fish.Circ., (129):7 p.

It has been prepared for distribution to individuals and agencies concerned with or engaged in water- and land-use development as well as to fishery workers. Arranged in tabular form, it describes: (i) some of the usual ways in which water and land development harms aquatic resources, and (ii) ways to avoid or reduce such damage. The descriptions are brief and intended to serve only as a useful warning and guide, not as a substitute for on-site investigation and analysis by professional biologists. Decision makers are urged to review their existing and planned projects with these risks to fisheries and other important aquatic resources in mind.

The authors of this document have had extensive (world-wide) experience with the effects of water- and land-use on fresh water, anadromous and estuarine fisheries. In addition to work with the California Department of Fish and Game, much of it occupied with the fishery aspects of hydroelectric power development, Mr. Dill served as Chief of FAO's Inland Fishery Resources Branch and as Secretary of the European Inland Fisheries Advisory Commission (EIFAC). Mr. Kelley, formerly research director of the State of California's San Francisco Bay and Delta fishery studies, also served in the Operations Service of FAO's Department of Fisheries at Rome Headquarters and in the field, where he was concerned largely with the operation of Special Fund Projects of fishery investigation and development on African rivers and man-made lakes, under the United Nations Development Programme (UNDP). Mr. Fraser, former Chief of the California Department of Fish and Game's Water Projects Branch (now the Environmental Service Branch), and former Chairman of the Environment Protection Authority of the State of Victoria, Australia, has also been a fishery consultant for FAO.

The authors are grateful for suggestions by fellow workers, especially Mr. Willis A. Evans of the U.S. Forest Service, San Francisco, CA; and Dr. V.R. Pantalu, Fishery Advisor to the Mekong Secretariat of the United Nations Economic Commission for Asia and the Far East (ECAFE) in Bangkok.

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Bibliographic entry:

Dill, W.A., D.W. Kelley &
J.C. Fraser (1975)
FAO Fish.Tech.Pap., (141):10 p.
Water- and land-use development and the aquatic environment - problems and solutions

Water resources. Land resources. Resource development. Agriculture. Fisheries. Aquaculture. Dams. Fishways. Reservoirs. Introduced species. Stocking. Water quality. Quality control. Dredging. Estuaries. Sedimentation. Migrations. Artificial spawning. Selected bibliography.

WATER- AND LAND-USE DEVELOPMENT AND THE AQUATIC ENVIRONMENT - PROBLEMS AND SOLUTIONS

Water resource and land development projects disrupt or modify hydrological cycles and existing patterns of water- and land-use, and thus often have negative or deleterious effects on the aquatic environment and its living resources. Nevertheless, it is often possible to offset, completely or partly, some of these negative effects if:

(i) a review of possible problems is initiated early in the planning of the project;

(ii) the problems are accurately identified;

(iii) the problems are investigated in the field (this may involve extensive study and require considerable time);

(iv) recommendations by investigators and planners are prepared and submitted before completion of project plans;

(v) the recommendations are implemented with appropriate timing in relation to project development and operation; and

(vi) there are one or more post-project reviews to ensure that the recommendations have been properly implemented and are accomplishing their intended purposes.

Furthermore, with proper study and genuine cooperation, changes can sometimes be made that lead to overall enhancement of the living aquatic resources. (To man, usually the most significant of these resources are fish stocks of importance economically either for food or recreational use.)

The table that follows provides a list of various water-and land-use activities, their effects on aquatic resources and some possible solutions to problems created. Generally speaking, the outline is concerned primarily with biological and engineering questions rather than sociological ones.

A note of warning must be entered here. The relative simplicity of the table should not lead the reader to believe that the problems are usually simple or that they have simple solutions. Furthermore, the severity of the problems and the methods of solution may differ decidedly in developed and developing countries.

It must be pointed out that in many of the examples given the question of alternate use or alternate development should be explored. For example, a lagoon or estuary may well have a greater value as a fishing area or contributor to a fishery (if it constitutes a fish spawning or nursery area) if left in its aquatic state rather than turned into a land area. It may be possible to achieve the intended water development through an alternate project feature with less damaging effects on the fishery resources.

In some instances the value of an aquatic habitat in its natural condition may be so great or so irreplaceable that a development scheme should not be approved.

In the long run, the successful resolution of conflicting objectives in the use of water and land lies in better understanding of these objectives and associated problems by the different interests (e.g., agriculture, fisheries, hydropower) and men of different disciplines (e.g., engineers, biologists, economists) involved, and their willingness to cooperate.

Development Activity	Possible Negative Effect	Possible Solution
(1a) Dam or barrage construction	Barrier or deterrent to upstream movement of fish - especially serious with respect to migratory fish which depend upon reaching certain stream, lake or estuarine areas utilized as spawning or nursery grounds.	(i) Installation of a passage over or through the dam (e.g., fishway, fish lift or fish lock). (ii) Transportation (e.g., trucking) to a point above the barrier.
(1b) Dam or barrage construction	Deterrent to downstream migration - especially of young migratory fish. Stream fish often cannot find their way through a large reservoir and if they do, they may find no suitable downstream escape route through or over the dam.	(i) Regulations of flow (or drawdown) to attract fish downstream. (ii) Modification of dam outlets and spillway to allow fish passage over or through the dam (coupled with provision of suitable basal pools); creation of special exits such as flumes or by-passes or modification of fishways or provision of collecting points for young fish for transfer downstream. (iii) Employment of special devices or methods (e.g., artificial currents, lights, bubbles, vibration, electricity, etc.) to direct downward migrants to safe exits. (Solution often difficult.)
(1c) Dam or barrage construction	Deposition of sediments in downstream areas and turbidity during construction. Turbidity is usually temporary but the deposition of sediments in the stream bed below storage reservoirs often destroys habitat for years (see also(5)).	Recognition of the danger prior to construction. Place controls on the construction process; bind contractor legally to prevent such damage.
(1d) Dam or barrage construction	Reduction or elimination of a salinity gradient required for upstream or downstream migration of fish or other aquatic organisms.	Preservation or creation of an alternative migratory route with an artificially created salinity gradient.
(2a) Impoundment and/or diversion or abstraction of water	Loss of the original stream fishery within the reservoir basin. Alteration of upstream fish fauna because of migrations of fish from the reservoir.	Development of a fishery in the new reservoir (man-made lake). For example, although it is often enough to merely await the development of fishable stocks from species already resident in the impounded drainage, it may also be useful to add to or replace some of the components of the original assemblage of food and/or sport fishes.

	Development Activity	Possible Negative Effect	Possible Solution
(2a)	Impoundment and/or diversion or abstraction of water	(See p. 2)	Efforts may also be made to change the composition of other faunal (or floral) assemblages such as plankters, benthic invertebrates, forage or predatory fishes. Note that care must be exercised in selecting new (i.e., non-native) aquatic species for introduction into a reservoir or elsewhere throughout the basin because of possible adverse effects on upstream and downstream faunal relationships. Other aids to development of fish populations (listed in the tables that follow) include installation of spawning devices, improvement of shelter, vegetation control, and destratification. Fishing for food species using nets may be facilitated by clearance of trees and brush prior to impoundment. Conversely, the addition of fish attractors may be useful in improving fishing for either food or sport fish. Exploratory fishing may be necessary to locate fishable stocks as may experimental fishing to determine the best types of gear and methods of harvest. Provision of access roads and launching and landing facilities (e.g., wharfs) may be necessary for fishery development of the reservoir. With respect to food fish, processing facilities, storage, and marketing and transport systems are also necessary. Management of the fishery on the basis of sustained or optimum yield usually requires continued fishery investigation, installation of a statistical collection system, and formulation and enforcement of fishery regulations.

	Development Activity	Possible Negative Effect	Possible Solution
(2a)	Impoundment and/or diversion or abstraction of water	(See p. 3)	It is important to note that in developing countries, an investment in research and training, as well as provision of capital, is necessary to accomplish the above objectives. Aside from the development of a fishery in the major reservoir which has been created, it may be possible to establish aquaculture in other areas (especially irrigated ones) using some of the water diverted from the stream.
(2b)	Impoundment and/or diversion or abstraction of water	Reduction of the downstream fisherman's ability to catch fish because his traditional gear and boats are no longer adequate to cope with the changed environment or different species of fish.	Investigation of new needs, training and provision of different equipment.
(2c)	Impoundment and/or diversion or abstraction of water	Reduction of flow in normal stream channel below dam, with a consequent reduction of living space and spawning and nursery grounds, changes in food production zones, etc. Reduction of flood flows will reduce the size of overflow areas (ditches, swamps, oxbows, etc.), and restrain lateral migration by mainstream fish into the formerly inundated areas - thus lessening total fish production through losses in recruitment and available spawning, nursery and feeding areas. Productivity in the main stream can also be lessened through diminished inflow of organic matter from the formerly inundated areas. (Such changes are particularly harsh on the "warm-water fishes" of both temperate and tropical regions.)	(i) Provision of adequate flows of water, especially at critical times of year or even day.

	Development Activity	Possible Negative Effect	Possible Solution
(2c)	Impoundment and/or diversion or abstraction of water	Conversely, reduction of flow may be harmful in some streams by diminishing the normal pattern of flushing action which serves to keep channels clear for fish migration and prevents the encroachment of riparian vegetation which may diminish fish habitat and make (sport) fishing difficult.	
		Abnormal augmentation of flow (which may also be a concomitant of water impoundment or diversion) can cause severe flushing and erosive action.	
		Fall in water level below a dam may uncover barriers to upstream movement and inhibit downstream migration of fish.	Removal of exposed barriers
(2d)	Impoundment and/or diversion or abstraction of water	Changes in velocity of water with consequent effect on holding position of fish, their feeding, spawning, etc.	As above. Installation of devices to increase or decrease velocity.
(2e)	Impoundment and/or diversion or abstraction of water	Change in water quality below dam (e.g., discharge of dissolved toxic gases or water with low oxygen) with consequent injury to fish (see also (5) below).	(i) Regulation of time, place, and amount of discharge. (ii) Destratification of the reservoir by various means, to improve water quality. (iii) Clearing of vegetation from reservoir. (iv) Re-aeration below dam.
(2f)	Impoundment and/or diversion or abstraction of water	Changes in water temperature which affect survival of particular species, or spawning, food production, etc.	Selective water release from surface or lower levels of the reservoir, through installation of multiple outlets or changes in chronology of release.
(2g)	Impoundment and/or diversion or abstraction of water	Disappearance of shrimps, oysters, and other estuarine species through changes in the seasonal salinity gradient or reduction of food supply as floods decline.	(i) Modification of the stream flow releases to accommodate various environmental requirements of the estuarine fauna. (ii) Relocation of the fishery. (May require different boats and gear.) (iii) Substitution of aquaculture of various kinds.

	Development Activity	Possible Negative Effect	Possible Solution
(2h)	Impoundment and/or diversion or abstraction of of water	Fluctuation of water level in reservoir above dam. May strand fish, reduce living space, destroy vegetation, change or reduce food components, influence spawning adversely, produce changes in habits inimical to stocks, etc.	(i) Regulation of levels to provide "minimum pool", and/or more constant conditions at critical seasons. (ii) Construction of secondary impoundments. (iii) Salvage of stranded fish. (iv) Substitution of artificial vegetation or substrates (if required, say, for spawning).
(3a)	Diversion or abstraction of water from streams or reservoirs	Loss of fish which enter diversions (canals, penstocks, etc.). Physical damage to fish passing over dams.	(i) Installation of mechanical fish screens (stationary, rotary, belt-type, travelling, louver, etc.), or electrical deflectors or screens. (ii) Use of by-passes in diversions to enable fish to return to streams.
(3b)	Diversion or abstraction of water from streams or reservoirs	Transfer of unwanted fish from one drainage to another. Mixing of stocks otherwise desirable (inter-basin transfers).	(i) As in (3a) above. (ii) Elimination of unwanted fish from a stream above its diversion point, usually by use of toxicants. (Note that solutions to this problem are difficult - in fact, rarely successful. For example, fish screens are never 100 percent efficient; toxicants frequently fail to remove all the unwanted fish. The effect of possible introductions should, therefore, be carefully assessed during the planning stages.)
(4)	Drainage and dredging or land-filling of water and wetland areas (estuaries, lagoons, marshes, overflow areas, etc.). Modification of stream courses, removal of gravel, deposition of spoil, logging debris, etc.	Destruction of habitat, spawning areas, food-producing zones, etc. Creation of barriers or deterrents to fish migration.	(i) Prevent damaging drainage. (ii) Attention to preservation of natural features of streams, e.g., contours or meanders rather than straight chutes. (iii) Provision of adequate flows to maintain overflow areas. (iv) Ban on removal of gravel necessary for spawning. (v) Removal of debris. (vi) Removal of unnatural barriers. (vii) Installation of devices to permit migration (e.g., through road culverts).

	Development Activity	Possible Negative Effect	Possible Solution
(5)	Any activity resulting in water pollution. (Pollution with respect to fisheries includes all harmful changes in water quality, including excess heating, salinization and siltation as well as the introduction of toxic substances, pesticides, oxygen-consuming materials, radio-active wastes, etc. Thus road building, logging, irrigation return, and discharge from thermal plants may contribute to pollution.)	Degradation of aquatic habitat (as through silting, which destroys stream bed organisms, renders spawning gravels less permeable, etc.), destruction of food organisms, deterioration of fish stocks, changes in species composition, mass destruction, establishment of residues in fish flesh which are harmful or objectionable to consumers.	(i) Control of siltation through reforestation, cover cropping, terracing, contouring, better road location, soil stabilization, etc. (ii) Removal of silt from channels through various devices. (iii) Control of other forms of pollution by pre-treatment of effluents, timing of discharges land disposal of pollutants, redesigning of processes to alter quality and quantity of effluents, better location of plants, re-use of wastes, etc. (iv) Ban on use of certain pollutants.
(6)	Any of the above which reduce fish stocks or habitat.	Reduction or change of habitat to such an extent that the natural wild stocks have declined to a point of almost no return.	Replacement or augmentation of fish stocks through: (i) artificial stocking; (ii) operation of artificial spawning areas. Such means may involve the construction and operation of new fishculture facilities for collection, holding, spawning, hatching, rearing, and transport. If study shows that the decline in natural stocks (due to the development project) will be severe, provision for some or all of the above measures should be an integral part of the project. If it is indicated that reliance on such measures will not be able to offer adequate replacement of the decimated stocks, then consideration should be given to other forms of compensation as an integral part of the project.

ANNOTATED BIBLIOGRAPHY

The references listed here have been selected to provide the reader with broad reviews of the subject and to lead him to related technical literature covering such aspects as: fishways, protective devices for fish at water diversions, provision of adequate flows in streams for aquatic life, etc.

Bell, Milo C., Fisheries handbook of engineering requirements and biological criteria. Fisheries-Engineering Research Program, U.S. Army Corps of Engineers, North Pacific Division, Portland, Oregon, 511p.

A handbook prepared for use by engineers and biologists employed in design problems on fish facilities and in the operation of such facilities. It sets forth limits in design for estimating procedures. Contains many tables, graphs and formulae for estimating or calculating dimensions, flow requirements, and other criteria.

Clay, C.H., 1961 Design of fishways and other fish facilities, including: fish locks, fish elevators, fences and barrier dams, fish screens, artificial spawning channels. Ottawa, The Department of Fisheries of Canada, 301p.

A definitive treatise providing information on the above subjects not only to engineers but to a wide variety of workers concerned with problems of fish migration and their protection. Includes a section on the special knowledge of hydraulics useful in ensuring fish propagation.

Dill, W.A. and G.L. Kesteven, 1960 Methods of minimizing the deleterious effects of water- and land-use practices on aquatic resources. In IUCN/FAO (1960):271-307

Reviews the practical techniques that - applied to environments or stocks - may prevent, alleviate or capitalize on the consequences of environmental changes induced by water- and land-use practices, and presents suggestions as to how the acceptance of these measures can be achieved in the face of conflicting objectives.

Dill, W.A. and T.V.R. Pillay, 1968 Scientific basis for the conservation of non-oceanic living aquatic resources. FAO Fish.Tech.Pap., (82):15p.

Concerned with the application of scientific knowledge to improve production of inland aquatic resources, particular attention is called to the need for participation by fishery scientists from the early stages of planning and execution of land and water development projects and the cooperation of agencies concerned with resource management. (Updates Dill and Kesteven, 1960, to some extent).

This paper was also published in 1970 by Unesco as p.87-104 in Use and Conservation of the Biosphere. Proceedings of the Intergovernmental Conference of Experts on the Scientific Basis for Rational Use and Conservation of the Resources of the Biosphere, Paris, 4-13 September 1968. Natural Resources Research X. Paris, Unesco, 272p.

FAO, Department of Fisheries, 1968 The role of FAO in the development of inland fishery resources. FAO Fish.Tech.Pap., (81):6p.

Prepared for the International Conference on Water for Peace, Washington, D.C., U.S.A., 23-31 May 1967, as Paper P/651. Shows that inland fisheries may make a high contribution to food supply and natural income. Discusses in part problems of inland fishery development as related to water resources development.

Fraser, J.C., Regulated stream discharge for fish and other aquatic resources - An annotated bibliography. FAO Fish.Tech.Pap., (112):103p.

A review of the readily available literature on the question of how to establish or select adequate minimum flows for fish life in streams which have been brought under complete or partial control by dams and diversions.

_____, 1972 Water levels, fluctuation and minimum pools in reservoirs for fish and other aquatic resources - An annotated bibliography. FAO Fish.Tech.Pap., (113):42p.

Presents the readily available literature dealing with the effects of reservoir (man-made lake) fluctuations and pool levels on fish and other aquatic life as an aid to those searching for answers to related reservoir management problems.

_____, Determining discharges for fluvial resources. FAO Fish.Tech.Pap., (143) (in press)

A comprehensive review of the methods and approaches used to determine adequate controlled streamflows for maintenance of fishery resources.

IUCN/FAO, 1960 International Union for Conservation of Nature and Natural Resources, Seventh Technical Meeting, Athens, September 1958. Vol.IV. Soil and Water Conservation, Natural Aquatic Resources, 374p.

Contains many papers on the effect of land- and water-use and their development on the aquatic environment and its living resources.

Lagler, K.F. (Ed.), 1969 Man-made lakes, planning and development. Rome, FAO, 71p.

"This document is intended as a guide for use in the earliest stages of planning a man-made lake to minimize human stress and maximize the overall social and economic achievement through timely consideration of secondary aspects".

Sharma, Rajendra K., 1973 Fish protection at water diversions and intakes: a bibliography of published and unpublished references. Environmental Statement Project, ANL/ESP-1, Argonne National Laboratory, Argonne, Illinois, 33p.

Contains 204 references, classified as to content, concerning guidance of fish at water diversions and screening them at intakes. Emphasis is placed on the protection of fish at power plant intakes.

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MI/H0497/E/7.75/1/900